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# The role of burrowing animals in the transport of mineral substances in the soil

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## 1. Introduction

The vertical migration of chemical substances is a frequent occurrence in the soil. This migration is associated not only with biotic cycle maintained by plants, the ascending and descending flow of water, but also with the mechanical action of burrowing animals.

The digging activities of most burrowing animals — such as moles, marmots, gophers, ants and termites — are confined to either deeply occurring illuvial soil horizons or soil-forming rock, both of which abound in various chemical substances. Burrowing animals bring soil material or soil forming rock to the surface and, together with them, the various chemical substances. These chemical substances move into the upper and most active soil layer, being deposited there and involved in the biotic cycle to exert their influence upon the soil. This transport of chemical substances in the soil from the deep to the upper layers, though attracting some attention (Dokučaev 1883; Dimo 1903, 1916, 1941; Bachter, Hole 1967), has so far escaped a thorough study.

The aim of this paper is to assess the part played by burrowing animals in the transport of chemical substance from deeper to upper layers of the soil. The present research was chiefly concerned with two species of burrowing mammals: moles (*Talpa europea* L.) inhabiting the deciduous-spruce forests of the Moscow Region and gophers (*Citellus pygmaeus* Pall.) occurring in the Janybeck clayey semi-desert of the Ural Region in the Caspian Lowland.

## 2. Methods

The amount of soil annually brought by animals from deeper layers to the surface and its chemical composition were calculated. This was done by collecting and weighing all the soil annually brought to the surface by animals on the test plots. The calculations were performed in terms of dry weight, the moisture content of soil samples being determined by weighing them before and after drying at 105 °C. Depending on the number of mole-hills, the total area under test for moles varied from 100 to 625m$^2$, while the total area under test for gophers was equal to 2500 m$^2$ (Abaturov, Deviatych i Zubkova 1969). The amount of soil brought out by moles was also calculated according to the number of mole-hills formed in 10 years and their weight (Abaturov 1966, 1968). An average sample of soil from freshly formed mole-hills was taken on each test plot for the chemical analysis of total composition (Si, Fe, Al, Ca, Mg) of gypsum, carbonates, exchange cations ($Ca^{++}$, $Mg^{++}$, $Al^{+++}$), etc. According to the data collected, the researches calculated how many and which chemical substances were brought to the surface by the animals under study, and thereupon, compared the results with the supply of the same substances through the litter-fall. The litter-fall supply was calculated from the biomass of above- and underground of the

1) The research was performed at the Laboratory of Forest Studies of the USSR Academy of Sciences.

plants on test plots (KAMENECKAJA, GORDEEVA i LARIN 1955) and from the content of mineral elements in them (BAZILEVIČ 1955, 1962) or else use was made of calculations already available (REMEZOV, BYKOVA i SMIRNOVA 1959).

## 3. Discussion

Moles in the decidnous-spruce forests with soddy podzolic soils transport to the surface up to 19 tons of soil per hectare per annum, in the meadows of Czechoslovakia, 55 tons per hectare (in terms of raw weight), and sometimes (incomplete data) even 160 tons per hectare (Table 1). It is noteworthy that, in the forest, moles transport soil to the surface only while digging burrows which occur deeper than 10 cm from the surface. While digging in the upper 10 cm layer, moles move soil apart, lifting is slightly without throwing it out on the surface. Therefore there is no soil from layers deeper than 10 cm in the mole-hills. In spruce forests with strongly podzolic soils, there are no mole-hills at all (Table 1).

Table 1 Amount of soil transported by burrowing animals in a year

| Species | Area and habitat | Plant community | Weight of dry soil, tn/ha* | Researcher |
|---|---|---|---|---|
| *Talpa europea* L. | Czechoslovakia, meadow | — | 55.0** | GRULICH, 1959 |
| *Talpa europea* L. | Moscow Region, forest | Betuletum pilosae caricosum | 18.6 | ABATUROV |
| *Talpa europea* L. | Moscow Region, forest | Tilietum pilosae caricosum | 12.7 | ABATRUOV, 1968 |
| *Talpa* | Moscow Region, forest | Quercetum pilosae caricosum | 3.9 | ABATUROV, 1968 |
| *Talpa europea* L. | Moscow Region, forest | Quercetum-Piceetum pilosae caricosum | 8.1 | ABATUROV, 1968 |
| *Talpa europea* L. | Moscow Region, forest | Piceetum hylo-comioso-pilosae caricosum | — | ABATUROV, 1968 |
| *Citellus pygmaeus* PALL. | Clayey semi-desert of Northern Caspian Lowland | *Artemisium pauciflora Kochia prostrata* | 1.5 | ABATUROV, 1969 |

* 1000 kilogrammes per hectare
** Raw soil

Small-size gophers in the clayey semi-desert of the Caspian Lowland succeed in transferring to the surface some 1.5 tons of soil per hectare annually (Table 1). Gophers burrow mostly on a saline solonetz in the friable sub-solonetz horizons at a depth of 40—200 cm, horizons which are especially saline.

It was confirmed on chemical analysis that the mole-hills consisted of material from deep layers of the illuvial horizon (30—40 cm deep), in which substances leached out of the overlying horizon tend to accumulate (Table 2). Therefore the soil of mole-hills was richer than the humus $A_1$ horizon in the most mobile chemical substances including sesquioxides, calcium and magnesium oxides, exchange calcium and magnesium. Yet, it was much lower than the $A_1$ horizon in carbon and nitrogen (Table 2).

Table 2 Chemical composition of soil mole-hills and soddy-podzolic soil in oak-spruce forest (Querceto-Piceetum pilosae caricosum)

| Horizon and depth in cm | | | Total composition, % by weight of dry soil | | | | | | Exchange cations, me per 100 g of soil | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | C | N | $SiO_2$ | $Fe_2O_3$ | $Al_2O_3$ | CaO + MgO | $a^{++}$ | $Mg^{++}$ | $Al^{+++}$ |
| | — | — | 0.94 | 0.06 | 77.6 | 4.3 | 11.4 | 2.32 | 6.0 | 1.8 | 1.8 |
| II | $A_1$ | 0–10 | 3.3 | 0.19 | 82.7 | 3.3 | 9.1 | 1.88 | 9.9 | 1.8 | 0.4 |
| II | $A_1$ $A_2$ | 10–22 | 0.7 | 0.05 | 77.6 | 3.3 | 9.1 | 1.60 | 3.8 | 1.4 | 1.8 |
| II | $A_2$ B | 22–32 | 0.2 | 0.03 | 78.1 | 3.8 | 11.1 | 2.12 | 6.5 | 1.6 | 4.2 |
| II | $B_2$ | 32–62 | 0.2 | — | 80.8 | 4.3 | 11.7 | 2.28 | 11.4 | 3.6 | 4.9 |

Note: I = Freshly formed mole-hills; II = Soddy-podzolic soil.

The soils of gopher hills also consisted of materials from deeper horizons and differed from upper horizons by being higher in readily soluble salts, gypsum and carbonates, and calcium and aluminium oxides (Table 3).

The soil brought to the surface by termites, ants, woodlice and certain mouse-like rodents was also high in the chemical substances which are found in abundance in deeper horizons of the soil (DIMO 1916, 1941, 1945; ZIGUL'SKAJA 1966; BACHTER and HOLE 1967; SALEM and HOLE 1968).

According to our calculations, the mole-hills-soil which had accumulated in one year contained 238 kg per hectare of Fe, 481 kg of Al, 129 kg of Ca and Mg; the soil of gopher-hills, 122 kg per hectare of Al, 49 kg of Fe, 77 kg of Ca, 14 kg of Mg, 16 kg of Na, 18 kg of S and also 25 kg per hectare of readily soluble salts, mostly ions $SO_4$, Na, Cl, Ca and 62 kg per hectare of Ca in poorly soluble compounds of gypsum and carbonates (Tables 4 and 5). The equivalent amount from the upper horizon (10 cm deep) of soils undisturbed by burrowing animals was considerably lower in these substances (Tables 4,5 ). Thus, there was an annual increment to the 10 cm deep layer, due to burrowing activities, of 53 kg per hectare of Fe, 95 kg of Al, 27 kg of Ca and Mg; to the upper horizon of a saline solonetz 10 kg per hectare of Al, 58 kg of Ca, 8 kg of S and also 24 kg of readily soluble salts. These increments as a rule exceed the supply of substances to the soil surface with the litter fall (0.6 kg per hectare of Fe, 3 kg of Al, 37 kg of Ca and Mg on a soddy-podzolic soil and 5 kg of Al, 15 kg of Ca, 3 kg of S on a saline solonetz as indicated in Tables 4 and 5).

In addition, in the mole-hills, there were 76 kg per hectare of C, 4.8 kg of N and 9.7 kg of exchange Ca, i. e. much less than in the equivalent amount from the upper horizon $A_1$ (0—10 cm). Thus, the upper 10 cm deep layer, including mole-hills, becomes low in these substances. However, the total content of organic carbon and nitrogen in the eluvial horizon ($A_1$ and $A_2$) practically remains the same, since the soil of mole-hills differs very little in content from horizon $A_2$, while the content of exchange Ca there even increases. The balance of organic substances seems to remain the same. Thus, the supply of organic substances to the surface which, as we earlier believed, allegedly increased as a result of moling (ABATUROV 1966, 1968), actually remained the same.

Thus, it may be safely claimed that, both on soddy-podzolic and semi-desert saline soils, the transport of mineral substances by burrowing animals from deeper to upper layers of the soil must exceed their supply in the litter-fall from vegetation which is supposed to be the main supplier of chemical substances to the surface. In the absence of the capillary upflow of dissolved substances from the ground waters to the surface, the burrowing activities of animals become the main factor in supplying mineral substances from deeper layers to the surface.

Table 3 Chemical compositon of soil of gopher-hills and saline solonetz in semi-desert Caspian

| Depth in cm | Composition of water extract, me/100 g | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total salts, % | $HCO_3^-$ | $Cl^-$ | $SO_4^{--}$ | $Ca^{++}$ | $Mg^{++}$ | $Na^+$ | Total $SO_4^{++}$ |
| I — | 1.68 | 0.46 | 4.99 | 19.9 | 6.47 | 3.95 | 14.95 | 42.99 |
| II 0– 10*) | 0.05 | 0.58 | 0.03 | 0.22 | 0.34 | 0.09 | 0.42 | 0.95 |
| II 10– 20 | 0.26 | 1.38 | 1.12 | 1.71 | 0.24 | 0.20 | 3.60 | 2.75 |
| II 20– 30 | 0.82 | 1.15 | 3.03 | 8.97 | 1.72 | 1.03 | 10.50 | 12.62 |
| II 30– 40 | 2.08 | 0.40 | 4.14 | 2.62 | 8.64 | 3.97 | 18.54 | 48.02 |
| II 40– 50 | 2.45 | 0.29 | 4.75 | 31.55 | 9.71 | 5.00 | 21.90 | 53.93 |
| II 50– 60 | 2.42 | 0.28 | 4.98 | 30.90 | 7.75 | 5.05 | 23.37 | 46.14 |
| II 90–100 | 2.14 | 0.29 | 5.61 | 25.78 | 4.36 | 3.89 | 23.55 | 36.35 |

Note: I = Freshly formed gopher-hills; II = Saline solonetz (from A. A. RODE i M. N. POL'SKIJ 1961).

*) 0–5 cm for total composition.

Table 4 Share of moles in the transport of chemical substances in soddy-podzolic soil, kg per ha per annum*

| | Total content (tons) | C | N | Si | Fe | Al | Ca + Mg | Exchange | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | $Ca^{++}$ | $Mg^{++}$ | $Al^{+++}$ |
| Content in mole-hills | 8.05 | 76 | 4.8 | 2,942 | 238 | 481 | 129 | 9.7 | 1.6 | 1.3 |
| Content in horizon $A_1$** | 8.05 | 263 | 16.0 | 3,107 | 185 | 386 | 102 | 15.9 | 1.6 | 0.3 |
| Balance of substances in 10 cm deep layer due to burrowing activities | | −187 | −11.2 | −165 | +53 | +95 | +27 | −6.2 | 0 | +0.8 |
| Supplied with litterfall*** | 3.23 | 1,810 | 34.0 | 15 | 0.6 | 3 | 32 | — | — | — |

* Data relate to oak-spruce forest (Querceto-Piceetum pilosae caricosum).
** In an amount of soil equal to the amount of soil in mole-hills.
*** According to N. P. REMEZOV, L. P. BYKOVA i K. M. SMIRNOVA 1959.

Table 5 Share of small-size gophers in transport of chemical substances in a saline solonetz.

| | Total | Substances retained in water extract | | | | |
|---|---|---|---|---|---|---|
| | | Total | $Cl^-$ | $So_4^{--}$ | $Na^+$ | $Ca^{++}$ |
| Content in gopher-hills | 1,500 | 25.2 | 2.60 | 14.4 | 5.1 | 1.8 |
| Content in 0–10 cm layer* | 1,500 | 0.8 | 0.02 | 0.1 | 0.1 | 0.1 |
| Balance of substances in 0–10 cm layer considering : burrowing activities | — | +24.4 | +2.58 | +14.3 | +5.0 | +1.7 |
| Supplied with litter-fall: above-ground part | 296 | — | — | — | — | — |
| under-ground part*** | 3,133 | — | — | — | — | — |
| total | 3,429 | — | — | — | — | — |

* The total composition was determined to a depth of 5 cm in an amount of soil equal to the amount of soil in gropher-hills.
** Interpolated from the average content of sodium oxides in the soils of the given zone.
*** To a depth of 40 cm.

Lowland

| $CO_2$ of carbonates, % | Total composition, % by weight on ignition | | | | | | |
|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | Loss on ignition |
| 1.13 | 72.41 | 14.82 | 4.76 | 1.82 | 1.79 | 1.73 | 5.24 |
| 1.54 | 64.40 | 16.69 | 6.12 | 4.29 | 1.86 | 2.26 | 6.50 |
| 2.04 | 63.66 | 17.58 | 6.07 | 5.27 | 2.97 | 2.29 | 8.17 |
| 3.04 | 62.12 | 17.85 | 5.92 | 10.66 | 1.62 | 3.24 | 9.43 |
| 3.65 | 61.89 | 17.00 | 5.44 | 9.70 | 2.17 | 2.78 | 8.64 |
| 4.98 | 59.18 | 15.38 | 4.87 | 9.24 | 2.56 | 4.01 | 8.21 |
| 5.97 | 61.96 | 15.23 | 4.39 | 8.87 | 2.69 | 2.59 | 91.0 |

A characteristic feature of such migration of chemical substances in the soil is that burrowing animals transport both water-soluble and water-insoluble substances, unlike all other agents which mostly carry substances in a state of solution. Therefore, owing to burrowing animals, the upper layers of the soil are enriched with primary, unweathered minerals, carbonates, gypsum and other water-insoluble and poorly soluble compounds.

The substances brought to the surface by burrowing animals are involved in the biological cycle constituting a major source of increment to that cycle.

The primary minerals brought to the surface by burrowing animals, i. e. into the zone of most intensive weathering, provide resources for weathering and soil formation.

Owing to the burrowing activities of animals, a considerable part of the elements disappearing from the surface by eluvial processes are returning there again. Thus, burrowing animals act to offset eluvial processes. Though possibly not changing the direction of these processes, they act as a sort of brake decelerating the outflow of substances from the soil and at the same time enriching the upper layer with certain nutrients.

In desert and semi-desert conditions the evacuation of readily soluble salts by burrowing animals to the surface leads to an increased salinisation of the upper layers of the soil. Gypsum and carbonates brought to the surface in large amounts by burrowing animals tend to accumulate in the upper layers due to their high solubility. Since they

kg per ha per annum

| Ca of gypsum and carbonates | Total content | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Si | Al | Fe | Ca | Mg | Na | $S/SO_4$ | Cl |
| 61.6 | 406 | 122 | 49 | 77 | 14 | 16** | 18/55 | — |
| 15.8 | 483 | 112 | 48 | 19 | 16 | 17** | 10/29 | — |
| +45.8 | − 77 | + 10 | + 1 | +58 | − 2 | − 1 | +8/+26 | — |
| — | 0.7 | 0.4 | 0.1 | 2.3 | 0.6 | 2.6 | 0.7/2.2 | 1.8 |
| — | 7.9 | 4.7 | 4.4 | 12.5 | 4.3 | 5.6 | 1.9/5.7 | 25.3 |
| — | 8.6 | 5.1 | 4.5 | 14.8 | 4.9 | 8.2 | 2.6/7.9 | 27.1 |

are important improvers of a solonetz, the process should result in the upper layers getting desalinised.

## 4. Summary

In soddy-podzolic soils, the soils of steppes, semi-deserts and deserts, chemical substances enter the upper layers not only as a result of the biotic cycle or capillary action in ascending solutions but also as a result of their mechanical transport by burrowing animals. Moles, marmots, gophers, ants, termites and other animals, while burrowing, move from deeper to upper layers of the soil a material enriched with various chemical substances. Thus, both water-soluble and insoluble compounds, including unweathered primary minerals, make their way ot the surface; whereas, when transport occurs by other media, only water-soluble substances get to the surface.

Moles in a forest with soddy-podzolic soils annually transport to the surface from a depth of 10–40 cm (on various plots of the forest) up to 19 tons per hectare of such material, while small-size gophers in a clayey semi-desert with a saline solonetz – some 1.5 tons from a depth of 40–200 cm. Thus, there is an annual increment in the upper (0–10 cm) layer of a soddy-podzolic soil in an oak-spruce forest of 47 kg per hectare of Si, 74 kg of Fe, 139 kg of Al, 36 kg of Ca and Mg; in the upper layer of a saline solonetz – 10 kg of Al, 1 kg of Fe, 58 kg of Ca, 8 kg of S, 24 kg of readily soluble salts and other compounds. The increment of these substances entering through the litter falls is lower. The material supplied by burrowing animals is poor in organic substances (C and N). Owing to this, there is a decrease in the content of organic substances in the upper 10 cm deep layer. However, as a whole, the balance remains the same in the eluvial horizon ($A_1$, $A_2$) of the soil. Thus, the activity of burrowing animals is a major factor in supplying numerous substances from the deeper layers to th e surface.

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